

# Green Energy from Space Solar Power – A Technical Feasibility Study

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**Abstract—** *This paper describes the importance, general principle and main factors that must be considered in the design of a system both onboard as well as the ground segment, for a Space Solar Power system. Also explained are the design and realization of a functional demonstration model of the system (microwave to DC), especially the detector circuit that is part of rectenna system, which converts microwave energy into electricity.*

**Index Terms—**Space Solar power, Rectenna, Schottky diode.

## I. INTRODUCTION

Almost 90% of today's energy comes from burning fossil fuels (oil, coal and natural gases), which produce carbon dioxide, currently the major contributor to climate change (Global warming). New power plants of different sizes with different technologies are being built, but the environmental impacts of these plants are high. In the light of growing demands for energy and due to the fast depletion of conventional energy resources, worldwide search is now on for alternate energy resources.

The sun radiates about 1 trillion times the energy which the mankind consumes across the world today. If a small portion of this energy from sun can be extracted, it would be sufficient to secure the energy demands of our future. Space solar power is a potential source for the generation of large amount of clean power.

Traditional terrestrial based solar plants are used to extract solar energy to some extent but the space based solar power has many advantages over it. The solar irradiance is about 1.4 times in extraterrestrial level than at the surface of the earth because energy is not dissipated by atmospheric absorption. Also in the case of surface based solar power plants, the panels can collect solar power for about 6-8 hours a day only whereas for solar-based power plant the collection time is 24 hours and is not affected by weather

conditions. Space based solar plants would be more efficient and generate more power than land based systems.

One of the major advantages is that it could reduce Global warming. Solar power generation will not emit carbon dioxide and so would benefit the environment compared to thermal power. Space solar power will emerge as a serious candidate among the options for meeting the energy demands of the 21<sup>st</sup> century.

## II. BASIC CONCEPT

Space Solar Power (SSP) is the concept of collecting solar power in space where the means for collecting the energy will reside on an orbiting satellite instead of on the earth's surface. Capturing the Sun's rays in space to make electricity is already being done by hundreds of operating satellites. The major difference with this and SSP is that SSP will capture much more energy by means of solar cell array is converted into microwave power. It is transmitted to Earth by means of microwave beam with electronically steerable phased array antennas. The microwave energy is captured and converted into dc power. The capture and conversion process is jointly accomplished by a large non-directive aperture several square kilometers in area made from many small receiving apertures each terminated in an efficient solid state rectifier which are together known as rectifying antenna (rectenna). The rectenna arrays can be offshore at sea where they would actually stimulate fishing. In land, it can be a large green house whose roof is made of microwave collectors. It is then fed to the terrestrial power distribution grid. Figure. 1 shows the space based solar power collection concept and principal elements of Space based solar power transmission system.

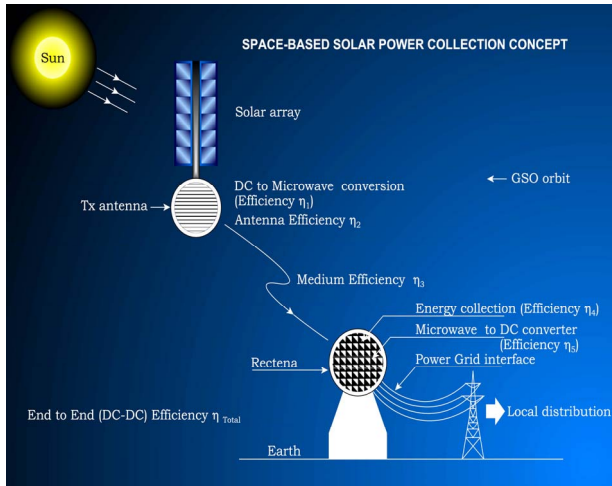


Fig. 1. Elements of Space solar power transmission

The major technologies to be focused in this area are Space based solar power plant and Earth based collection system. The overall system efficiency is the most important aspect to be considered in design of each system in the link. High power microwave generation and high efficient rectifier development are the major development areas in Microwave.

### III. ENVIRONMENTAL EFFECTS

The aspect of safety has to be paramount in microwave power transmission. The key environmental effects associated with SSP are those which could affect human health and safety, eco system and interactions with terrestrial electromagnetic systems. Permissible level for continuous, non occupational exposure to microwave radiation is  $1\text{mW/cm}^2$  and occupational exposure is up to  $5\text{mW/cm}^2$  for 8hrs/day. With properly controlled power beaming systems, it is unlikely that undesirable health and ecological effects would result. Experimental results show that up to a peak density of  $23\text{mW/cm}^2$ , the microwave beam would not adversely affect the performance of telecommunication systems. Figure.2 shows the suggested power distribution at the rectenna.

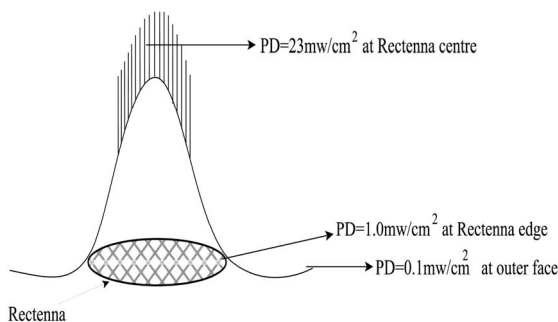


Fig. 2. Power distribution at the rectenna

At Earth's surface, the beam would have a maximum intensity at its center of  $23\text{mW/cm}^2$  and an intensity of less than  $1\text{mW/cm}^2$  outside of the rectenna fence line (the receiver's perimeter). It is important for system efficiency that as much of the microwave radiation as possible be focused on the rectenna. Outside of the rectenna, microwave intensities rapidly decrease. However techniques to control the transmitted beam retro-directive with the pilot signal from ground is a commonly proposed approach for ensuring fail-safe beam targeting. The reception centers are to be pre-designed offshore sites to reduce the safety issues.

### IV. CRITICAL TECHNOLOGIES INVOLVED

In the space based solar power plant, major focus should be in the areas like solar based power plant, earth based collection system and the medium of transmission from space to Earth. The aspect of efficiency and safety has to be paramount in the way energy is transmitted. The efficiency of the SSP is often stated in terms of the DC to DC efficiency, ie. DC voltage output at solar cells to the DC output of the rectenna and the major issue is achieving an overall efficiency  $> 75\%$ . Another important factor is the life / maintability of the solar power satellite especially the solar cells. Realization of high efficient, radiation tolerant, light weight solar cells and high efficient, high power microwave generators are the major development areas for the Solar power satellite. Large space antennas with excellent mechanical and phase steering stability properties with low mass and self deployable structures are also to be realized onboard. Systems/techniques to control the transmitted beam retro-directive with a pilot signal from ground is also an important milestone.

Another important factor is the cost of space based power plant, which is given by the current launch technologies, would be very high and needs to be brought down. The cost of space transportation which enables construction of large solar stations in space has to be brought down to  $1/100^{\text{th}}$  of its current value for enabling solar power stations economically sustainable.

### V. FREQUENCY OF OPERATION

Antenna aperture size, state of the art component availability, overall system efficiency including components, transmission medium effects and the impact upon users of the frequency spectrum are the factors generally considered while selecting the frequency. Transmission frequencies are generally limited to the ISM (Industrial, Scientific, Medical) bands (2.4 to 2.5 GHz and 5.8 to 5.9 GHz) where, 2.4 to 2.5GHz frequency is often preferred.

### VI. THE RECTENNA AS THE RECEIVING PORTION OF THE SYSTEM

The rectenna, or rectifying antenna is a unique device that was conceived and developed for beamed microwave

power transmission which combines the function of capture and rectification. Rectenna consists of an array of antennas connected to the rectifier diodes to convert the RF energy to DC voltage. A simple rectenna element consists of an antenna with a Schottky diode across the antenna elements. One of the major element which determines the overall system efficiency is the rectifier circuit. Different configurations operating at 2.45GHz were developed and optimized for better efficiency. Figure.3 shows the block diagram of the finalized configuration. The diode rectifies the AC current induced in the antenna by the microwaves, to produce DC power.

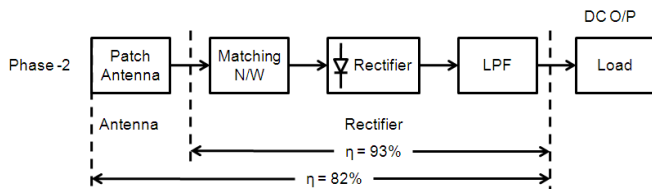


Fig. 3. Block diagram of Rectenna and Load

Schottky diodes are used because they have the lowest voltage drop and highest speed and therefore wastes the least amount of power for conduction and switching. The major factors to be considered while selecting the diode are voltage sensitivity (mV/mW), diode impedance and the tangential sensitivity. Efficiency of the diode rectifier also depends on the input power, frequency and the load impedance. The diode used for the experiment was MA4E2054. Diode is a nonlinear device and while rectifying, higher harmonics are generated. Input filter is provided to prevent the harmonics from flowing back through the antenna as well as for impedance matching. Output filter is also provided to prevent AC component appearing across the load terminal.

Different configurations were experimented and achieved an efficiency of 93% for the finalized configuration, which was realized on RT Duroid 5880, 20 mil substrate. Working models of the rectifier circuits with patch antennas are shown in Figure 4.



Fig. 4. Working model of rectenna

## VII. EXPERIMENTS AT GROUND SEGMENTS

To measure the efficiency of the rectenna in converting RF power to DC electricity under different conditions experiments were conducted using ground based setups. Figure 5. shows the test setup used for evaluating the rectenna. Ten rectenna elements are used for reception realized at 2.45 GHz. For simulating the microwave power, the signal generator output is amplified using a power amplifier and radiated using a horn antenna. Tests were conducted in the far field condition in an anechoic chamber. The elements DC outputs are connected in series parallel combination to drive a low power motor and LED indicator.



Fig. 5. Rectenna Test Setup

2W RF power was transmitted using a horn antenna (gain 13 dBi). In the scaled down model, a conversion efficiency of around 82% (Microwave to DC) was achieved.

## VIII. CONCLUSION

This paper reports on the design and realization of the functional demonstration model of rectenna, especially the detector circuit with efficiency more than 90% at S-band. Another important area for future development is the generation of high power source with very high efficiency. DC power combining of the rectifier output is another aspect to be considered. The highly skilled manpower and technologies/facilities available in India can be made use of design and development of cost effective energy from space.

## ACKNOWLEDGMENT

The authors thank Shri.Veeraraghavan PS., Director, VSSC, ISRO for his inspiring encouragement during the development of this design. They also thank Shri. Mookiah DD,AVN and Shri. John.P.Zachariah, AD RDP, VSSC for their valuable suggestions in implementing this. They express their gratitude to Shri. Y. Ashok Kumar (Rtd), Head RFD for his constant inspiration and guidance which made this working model a reality.

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